Wetlands (2016) 36 (Suppl 2):S223–S228
DOI 10.1007/s13157-016-0852-6

ORIGINAL RESEARCH

Midcontinent Prairie-Pothole Wetlands and Climate Change: an Introduction to the Supplemental Issue

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Received: 24 June 2016 / Accepted: 1 November 2016 / Published online: 9 November 2016

Abstract The multitude of wetlands in the Prairie Pothole Region of North America forms one of Earth's largest wetland complexes. The midcontinent location exposes this ecologically and economically important wetland system to a highly variable climate, markedly influencing ponded-water levels, hydroperiods, chemical characteristics, and biota of individual basins. Given their dominance on the landscape and recognized value, great interest in how projected future changes in climate will affect prairie-pothole wetlands has developed and spawned much scientific research. On June 2, 2015, a special symposium, "Midcontinent Prairie-Pothole Wetlands: Influence of a Changed Climate," was held at the annual meeting of the Society of Wetland Scientists in Providence, Rhode Island, USA. The symposium's twelve presenters covered a wide range of relevant topics delivered to a standing-room-only audience. Following the symposium, the presenters recognized the need to publish their presented papers as a combined product to facilitate widespread distribution. The need for additional papers to more fully cover the topic of prairie-pothole wetlands and climate change was also identified. This supplemental issue of *Wetlands* is the realization of that vision.

Keywords Biota · Climate change · Geochemistry · Hydrology · Prairie potholes · Prairie Pothole Region · Wetland ecosystems · Wetland landscapes

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Background

The Prairie Pothole Region (PPR) covers approximately 777,000 km^2 of the North American midcontinent (Fig. 1; Smith et al. 1964). Decay of the Laurentide ice sheet at the conclusion of Wisconsinan glaciation during the Pleistocene epoch (Dyke and Prest 1987) left behind a landscape formed of low-permeability glacial till dotted with innumerable depressions, i.e., potholes, that subsequently captured water and developed as wetlands (Fig. 2; Goldhaber et al. 2011). The more than 2.5 million wetlands in the PPR (Dahl 2014) constitute one of the largest wetland complexes in North America (van der Valk 2005; Keddy et al. 2009). Historically, wetlands covered approximately 16 to 18 % of the PPR (Dahl 1990). By the mid-1980s, approximately 60 to 65 % of the basins in this wetland system had been drained, mostly to facilitate agricultural crop production (Dahl 1990). The value of intact PPR wetlands in providing habitat for breeding waterfowl and other biota is widely known (Smith et al. 1964; Batt et al. 1989; Kantrud et al. 1989). More recently their role in providing other services valued by society (e.g., carbon sequestration, sediment and nutrient attenuation, floodwater storage) has been recognized (Gleason et al. 2008). However, despite their recognized wildlife and ecosystem service values, wetland losses in the PPR, while having slowed considerably, continue with an additional 18,340 ha of wetlands being lost between 1997 and 2009 (Dahl 2014).

The midcontinent location of the PPR exposes remaining wetland ecosystems to highly variable weather conditions (Winter and Rosenberry 1998), a result of influences by three competing air masses, Continental Polar, Maritime Polar, and Maritime Tropical, of greatly differing temperature and moisture contents (Bryson and Hare 1974). Shifts between periods of above-normal and below-normal precipitation (locally known as the wet/dry cycle) are common both across short

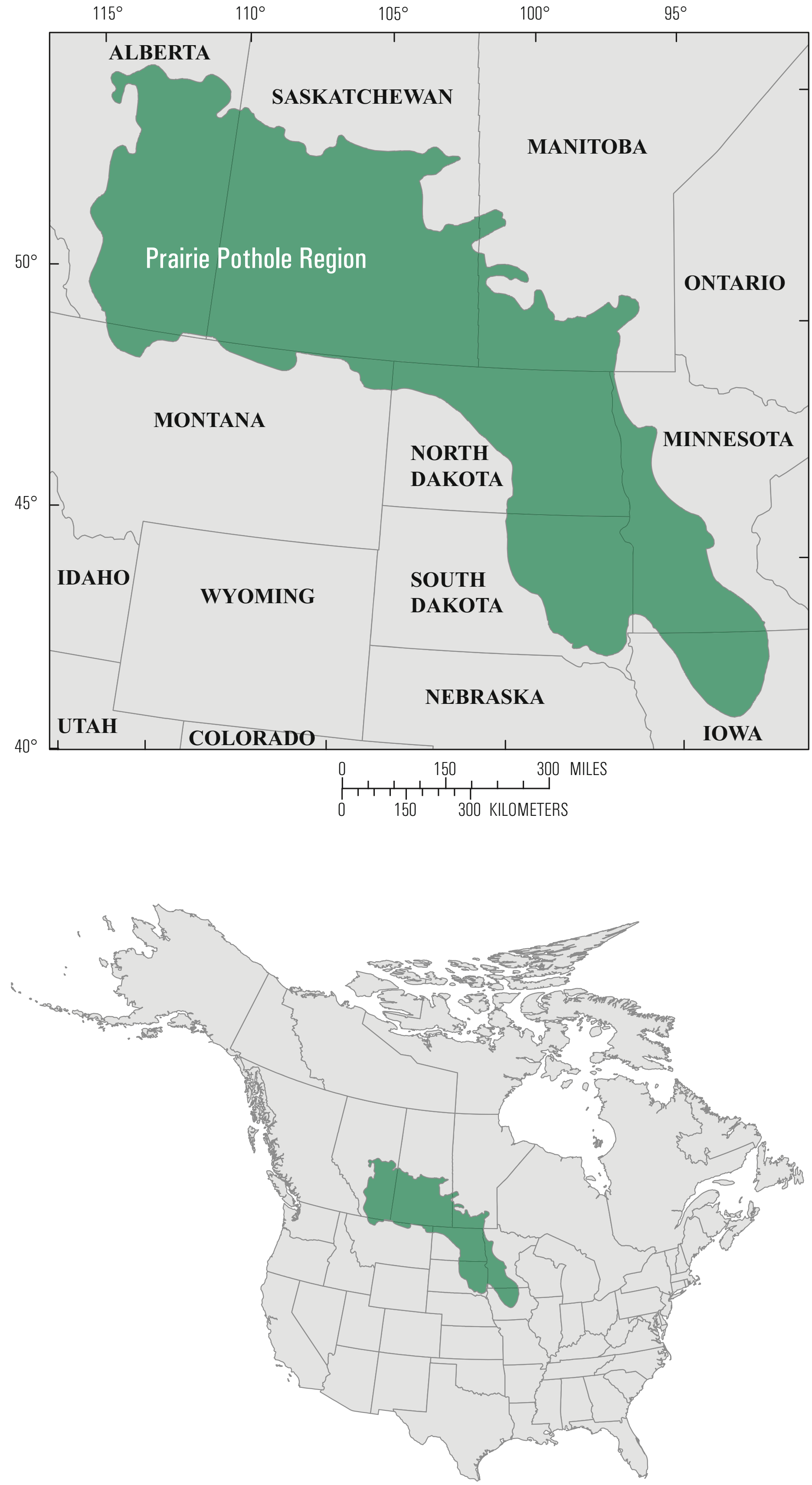

Fig. 1 Location of the Prairie Pothole Region in the midcontinent of North America (from Renton et al. 2015)

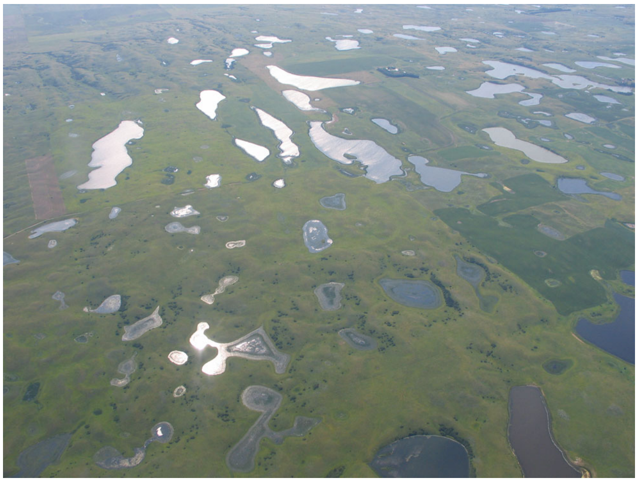

Fig. 2 Wetlands are a dominant landscape feature in the Prairie Pothole Region of North America

(e.g., Eisenlohr et al. 1972; Winter and Rosenberry 1998) and long (e.g., Fritz et al. 2000; Laird et al. 2003) time scales. Combined with a climate in which evapotranspiration typically exceeds precipitation (Winter and Woo 1990), great inter-annual variation in wetland water levels, both ponded (Fig. 3) and subsurface, result. These water-level variations have profound influence on the chemical characteristics, biota, and overall productivity of prairie-pothole wetlands (Euliss et al. 2004). Additional information on the PPR and its embedded wetland ecosystems can be found in reviews by Kantrud et al. (1989), van der Valk (2005), and Galatowitsch (2012).

Warming of Earth's climate is real (IPCC 2014), and there is strong scientific consensus of an anthropogenic cause (Cook et al. 2013) with resultant changes already having widespread impacts on natural systems (IPCC 2014). During the past century, the average minimum daily temperature in the PPR has increased by 1 °C and precipitation across the region has increased by about 9 % (Millett et al. 2009). Global surface temperatures are projected to continue to rise throughout the 21st century (IPCC 2014), influencing water losses from wetlands as evapotranspiration rates change in response to warmer temperatures. In addition to warming surface temperatures altering water losses and timing of snowmelt, extreme precipitation events (both flooding and drought) are projected to become more intense and frequent (IPCC 2014; Ryberg et al. 2015). Given the driving influence of inter-annual precipitation variation on prairie-pothole wetland ecosystems (Harris and Marshall 1963; van der Valk and Davis 1978; Winter and Rosenberry 1998; Euliss et al. 2004), an expanded knowledge base related to how changes in the timing, intensity, and frequency of extreme events will influence PPR wetlands is needed. The controlling influence of climate on many prairie-pothole wetland processes and functions underscore the essential need to understand potential influences of climate change on these systems.

Fig. 3 Climatic, and therefore hydrologic, variability is a defining feature of wetland ecosystems in the Prairie Pothole Region of North America. Aerial photos are of wetland P7 in the U.S. Geological Survey's Cottonwood Lake Study Area, Stutsman County, North Dakota

On June 2, 2015, a special symposium, "Midcontinent Prairie-Pothole Wetlands: Influence of a Changed Climate," was held at the annual meeting of the Society of Wetland Scientists in Providence, Rhode Island, USA. The symposium's twelve presenters covered a wide range of relevant topics to a largely standing-room-only audience. At a meeting following the symposium, the presenters identified the need to publish papers presented in the symposium as a combined product and thereby facilitate wide distribution and use. The need to include additional papers to more fully cover the topic of prairie-pothole wetlands and climate change was also identified. This supplemental issue of Wetlands is realization of that vision.

Overview of the Supplemental Issue

The supplemental issue begins with a paper by van der Kamp et al. (2016) setting the stage for an exploration into potential effects of climate change on prairie-pothole wetlands through a thought-provoking discussion of definitions and terminology used to describe these dynamic systems. Given the great inter-annual variation in ponded water and vegetation in these wetlands, van der Kamp et al. (2016) stress the need to focus on more stable, soil-based indicators of wetland boundaries. Additionally they highlight the need to move away from ambiguous terms such as "temporary wetland" and "semi-permanent wetland" towards descriptors that do not imply that these persistent landscape features are somehow transient and therefore easily disregarded. Instead, they stress the importance of clarifying that it is only the ponded water in prairie-pothole basins that may be temporary, seasonal, or semi-permanent, not the wetlands themselves that formed, and in many cases have persisted, following retreat of the Laurentide ice sheet.

The next two introductory papers, Hayashi et al. (2016) and Goldhaber et al. (2016), provide detailed overviews of the hydrologic and geochemical evolution, respectively, of prairie-pothole wetlands while providing results of recent research in the context of natural and human influenced climate variability. Hayashi et al. (2016) describe general climate and geologic settings that allow the multitude of prairie-pothole wetlands to exist. They include a summary of findings from long-term research sites in Canada and the United States, and end with a discussion of unresolved issues, including the impacts of wetland drainage on regional hydrology and suggestions for future research topics. Goldhaber et al. (2016) explore the geochemical changes that occur as prairie-pothole wetlands and lakes respond to climate variability, especially as related to extreme events such as drought and precipitation deluge. They use quantitative geochemical modeling techniques to highlight the role of precipitation as a major constituent driving lake geochemical evolution in prairie-pothole systems.

Following the introductory papers, Johnson and Poiani (2016) provide a review of past hydrologic modeling efforts that have greatly furthered our understanding of potential responses of prairie-pothole wetlands to projected climate change scenarios. The paper by Johnson and Poiani (2016) is followed by that of Liu et al. (2016), who use an integrated surface-subsurface hydrologic model to explore potential effects of climate change on PPR wetland hydrology. In Anteau et al. (2016), the authors stress the need to consider hydrologic impacts of landscape alterations that have occurred throughout the PPR in any assessment of future change. They emphasize the influence of wetland drainage on not just the drained wetlands but also on the aquatic systems receiving drainage waters. Recent changes in climate extremes combined with hydrologic alteration of landscapes within the region have resulted in prairie-pothole lakes greatly expanding in surface area and subsuming many nearby, and some not-so-nearby, wetlands. Vanderhoof and Alexander (2016) explore how lake expansion has influenced wetlands across the landscape of the PPR, in some cases increasing connectivity among aquatic systems, while in others, contributing to the loss of wetland functions when wetlands are entirely subsumed by an expanded lake. At a more localized scale, Leibowitz et al. (2016) identify differences between fill-and-spill versus fill-and-merge hydrologic processes and differing effects of each on the water chemistry and biotic communities of prairie-pothole wetlands.

The next set of papers explores climate-change effects on specific abiotic characteristics of prairie-pothole wetlands. LaBaugh et al. (2016) explore how solute sources of prairie-pothole wetlands have varied as a result of changing water levels and surface extent of wetland ponds leading to marked changes in solute concentrations. They use their observations to provide insights into how prairie-pothole wetlands might look in terms of solute concentrations under a warmer, drier, climate-future given previously observed changes in response to variable climate conditions. Cressey et al. (2016) revisited 80 central North Dakota prairie-pothole wetlands after 50 years to document climate-induced changes in wetland size, depth, and water chemistry. Bansal et al. (2016) explore wetland greenhouse gas fluxes through a detailed investigation into the effects of temperature and ponded water permanence on methane emissions from prairie-pothole wetlands. In a nod towards sustainability issues, Skagen et al. (2016) explore how sediments might enter wetlands at an accelerated rate under future climate-change scenarios, thereby putting at risk the future functionality of prairie-pothole wetland ecosystems.

The concluding set of papers in the supplemental issue focus on biotic effects. van der Valk and Mushet (2016) explore effects of variable water-level fluctuations on the vegetation of prairie-pothole wetlands and potential influences of changing amplitudes and frequencies of wet and dry events using simple sine-wave models. McLean et al. (2016a) evaluate the effects of recent increases in water depths and volumes of prairie-pothole wetlands and lakes on fish and salamander communities. In McLean et al. (2016b), effects of increased wetland and lake water levels on invertebrate communities are also explored. Stockwell et al. (2016) used genetic techniques to illuminate how changing wetland landscapes might affect the genetic diversity of a common amphibian, the northern leopard frog (*Lithobates pipiens*), and therefore its ability to adapt to changing environmental conditions. Steen et al. (2016) conclude the papers on biotic effects with their overview of potential influences of climate change on wetland-dependent birds of the PPR.

Taken as a whole, the papers included in this supplemental issue of *Wetlands* provide a unique consolidation of current knowledge related to potential effects of climate change on midcontinent prairie-pothole wetland ecosystems.

Acknowledgments This supplemental issue would not have been possible without the generous support of the U.S. Geological Survey Climate Research and Development Program, both in terms of sponsoring publication of the issue and in providing funding in support of several of the research efforts presented within. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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